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Energy Efficiency in historic buildings

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SCHOOL OF SCIENCE & TECHNOLOGY

A thesis submitted for the degree of

Master of Science (MSc) in Information and Communication Systems

December 2015

THESSALONIKI – GREECE



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Abstract

Are the historic buildings energy efficient? The logical assumption and answer is that they are not, due to their age and the old construction. But could these buildings be energy profitable? This is a challenge and lately a growing attention has been paid to the improvement of the energy performance. Although energy proposals are desirable, they are not possible without adjustments. The need to develop energy efficiency and sustainability in a cultural heritage building is presented in this dissertation. The aim is to display the particularity of these constructions and find ways which would enhance their energy performance but simultaneously do not change their appearance. A pilot case study of a historic building in the area of Ladadika, Thessaloniki, Greece is presented and analyzed in order to find remarkable results and opportunity for further developments.

I would like to acknowledge my supervisor Prof. Dimitrios Anastaselos for his wholehearted and effective support. He was there whenever I had to deal with a difficulty or a problem through my research. In addition, I would like to thank my friend Aris Kondilidis for his help in the case study. He gave me necessary information for the building and helped me with the floor plan. And finally, needless to say, I am deeply indebted to my parents, for their persistent support, as always.

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1 Introduction

Decades now, scientists pay attention and study historic buildings with target the energy efficiency of those buildings. Nowadays this is more critical than ever because, European regulatory has set some goals for reducing the energy consumption of the EU countries. Although it is not compulsory for the historic buildings of a country to follow this goal, by enhancing their energy performance these goals would be reached more easily. The major aim of the regulation is to preserve the environment and prevent climate change before it is too late. The initial package for 2020 sets three key targets: 20% cut in greenhouse gas emissions (from 1990 levels), 20% of EU energy from renewables and 20% improvement in energy efficiency. Statistics show that historic buildings consist more than the 25% of the buildings in European Union, meaning that catching the final goals until 2050 would be difficult unless this buildings not contribute.

For that reason this thesis aims to present a thoughtful proposal of a historic building in Ladadika, a historic area of Thessaloniki, Greece. In Greece historic buildings are many and vary, respecting the location, their use or their existing situation. The examined building in Ladadika is built in 1890-1900 and has been saved from the Great Fire in 1917.

In the *first chapter* a literature review is presented and refers to historic buildings in Europe and Greece which have already been studied. Refurbishment methods and also their results in every occasion are displayed. The *second chapter* notices the special category of these buildings. So specific Directives and Laws protect these constructions and define to what extend could be touched and change. The regulatory point of view in Europe and in Greece is presented.

The *chapter four* mentions the restoration techniques of the listed buildings and what methods of interventions do exist. Moreover, these techniques are analyzed and specialized in specific cases. In the end of this section renewable sources play important role as a method of renovation.

All the research for the thesis starts typically on the *fifth chapter*. A pilot case study of a listed building in Thessaloniki, Greece is displayed. In the beginning, a description of the area, where the building is, is presented. Ladadika is a remarkable area of Thessaloniki with over 100 listed buildings. To continue with, the examined building is showed and also the main elements and characteristics are emphasized. The U-values of the existing elements help us to propose specific interventions. Subsequently, the proposals are presented in detail and give us results. The results are summarized into tables and show the situation before and after the interventions.

As a conclusion, the contribution of this paper to the energy performance of historic buildings in Greece is assessed and a discussion about the results has been declared. Some graphs compare and highlight the differences and the improvement of the situation.

2 Literature Review: Historic Buildings in EU countries and refurbishment methods

The refurbishment of a building may seem easy and familiar nowadays but as far as historic buildings concern there should be some cautions. Protected buildings cannot be destroyed, redecorate or change their use with one that will not be compatible with their historical significance. The activities which can be set should be suitable and limit the risk related to cultural goods and maintenance include interventions which will control conditions of functional efficiency. There are some remarks and boundaries referring to the energy retrofitting of the old buildings. There are differentiations with the typical existing buildings. Historic buildings, are extremely energy consuming due to their age, their construction elements, the lack of maintenance all the previous years and limited efficiency of the energy systems that supply the building.

In addition, the approaches most times are similar. Firstly there is an assessment of the current situation, calculating the consumption and the energy behavior of the building. Then proposed interventions are presented and results are given. A major important fact is that different elements should be used considering the area and the climate where a building is constructed. Finally, renewable energy sources play significant role and allow an improvement in the energy efficiency but they are depending on the level the interventions can be, respecting the historic value of the building.

In the next pages, different case studies will be presented but the main target remains the same: Energy efficiency of historic buildings. The differences are noticed in the building's structure, the approaches selected, and the proposed interventions.

2.1 Energy efficiency through examples: Case Studies

It is noticed that, many heritage sites and buildings remain unexploited and have no essential use. For example in Norway, about 5,700 historic buildings are protected but the disuse may not be a long-term proposal for protection. Taking into account that, evaluation, assessment and enhancement of a historic construction may affect many parameters. The next case study tries to include as many as possible and with 9 aspects wants to give a completed opinion. To test this approach, Værnes Hovedgård, a 19th-century manor house with legal protection since 1934, owned by the Armed Forces of Norway, was selected. Evaluation of a historic building may reach as far as someone wants to penetrate, so the parameters may be too many. Social, economic, aesthetic, architecture, ecological, cultural, scientific, energy performance are some of them. For this reason, in Norway, DIVE evaluation tool by Riksantikvaren is used for assessing historic sites.

To continue with, the study started by selecting these 9 parameters of evaluation, which are, history, architecture, structure, environment, legislation, plans, time, users, economy. By implementing this aspects into the Værnes Hovedgård the researchers led that the architecture value is enormous and it is challenging to find proper use due to lack of facilities. As it is known the building is been protected by law but also does not perform any function. The property belongs to the armed forces and for that reason the building may have possible use as offices in the future, but only in legitimate ways. Some measures for that use are insulation measures which help for conservation and thermal comfort. Summing up, this research touched the most common aspects of evaluating a building which is the first step of beginning an energy improvement in a building, and clearly shows that the parameters are too many to be no appreciable. (Mari Oline Giske Stendebakkena, 2015)

In Italy about 20% are heritage buildings constructed before 1919. (Anna Laura Pisello, 2014) In the country, the ‘green retrofitting’ manage to improve this heritage and contribute to the goals that EU has set. On the one hand the renovation of historic buildings aim to the reduction of energy consumption and the energy saving through renewable systems, but on the other hand the target is to be the buildings more sustainable. In detail, green retrofitting contains the building’s envelope energy performance enhancement, the handle of natural ventilation, and passive cooling. In addition, the monitoring

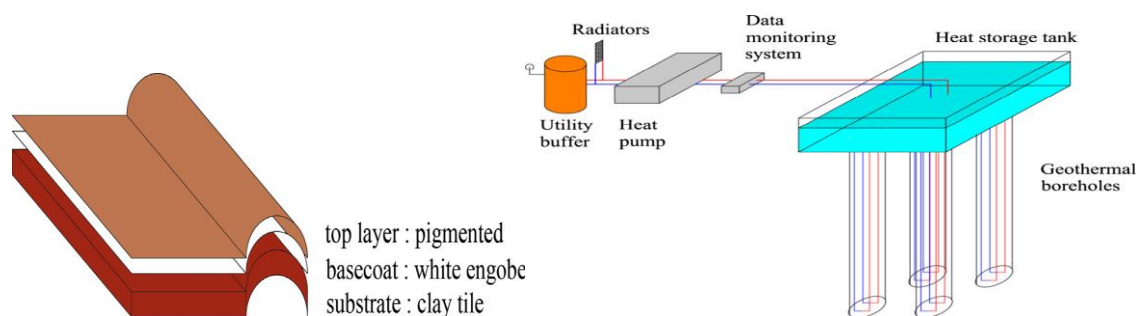
of the indoor quality, the water consumption, the replacement of existing energy systems with new more environmentally friendly and the use of recyclable materials.

The most important factor for green retrofitting are the needs of every building. (Filippi, 2015) The environmental conditions and quality depend on the use of a historic building and so the needs vary. For example, before 19th century heating systems didn't even exist so in the restoration would be an installation, or for buildings after 1900 the HVAC systems could be replaced from ones more efficient and with lower consumption. The insulation also, sometimes is non-existent and sometimes a new one must be added.

2.2 Major interventions in historic buildings

So, the main steps for a successful refurbishment of historic buildings include implementation of internal insulation, new glazing in the windows and cooling coatings. As far as the technologies are concerned, ventilation, lighting and thermal storage are considered to be the most popular during the last years. All these have target the reduction of energy demand ("demand side" management point of view). Moreover, the renewable energy systems are able to dominate in enhancement of the building performance and dwell the "supply side" management point of view.

An interesting approach took place in the center of Perugia, in a historic university building, the Palazzo Gallenga Stuart. The purpose of this study was to implement innovative and integrated techniques, in respect of the historic architecture, in the view of sustainability and energy savings. The opaque envelope is composed of bearing stone blocks masonry, brickwork finishing and internal cement plasterboard. The building has a hot water radiator distribution for heating, and condensing external units with fan-coils for cooling. To begin with, the refurbishment include implementation of low impact cool clay in the roof (passive technology) and a geothermal heat pump system with a storage tank (active technology). (Picture 1)

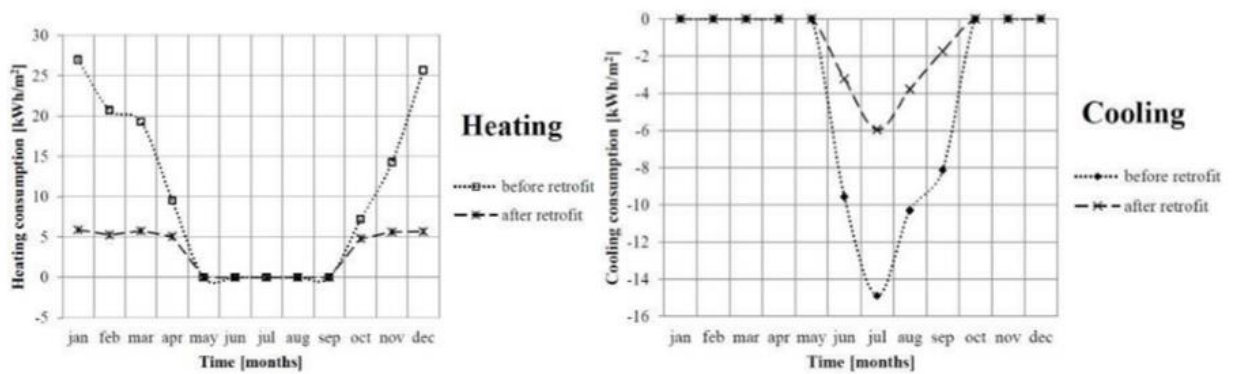


Picture 1: *Passive and active used technology for the restoration of Palazzo Gallenga Stuart.*

Four scenarios were taken into consideration and environmental impacts and assessment exported. Finally, there was a cost analysis of the whole project. In the first scenario, only the passive retrofit was implemented, and the cool tiles lead to a 2, 4% energy saving for cooling in the whole structure. In spite of this small percentage, the analysis of the indoor comfort was encouraging in the classes, meaning that this scenario is effective in specific thermal zones of the building.

Scenario two indicates the energy assessment after the active energy retrofit strategy. The ground heat pump manages to succeed reduction about 64% and 67% of heating and cooling energy consumption. In the third scenario, both active and passive retrofits are combined and result a cooling energy saving of 69.2%, and a heating energy saving of 64.0%.

Comparing these three scenarios we can deduce that passive and active retrofits operate better together. Despite the fact that in summer months cooling tiles can improve the energy performance and guarantee a passive cooling effect, in winter the heat pumps can reduce effectively the consumption and demand. In addition, the environmental analysis noticed that from scenario 1 to the scenario 3, the CO₂ emissions are reduced by 82%.



Picture 2: Annual primary energy need for heating and cooling of “Palazzo Gallenga” (a) before the energy restoration and (b) after the energy restoration.

According to the graphs above (Picture 2), the energy retrofit managed to accomplish a reduction almost in half the initial consumption without the interventions in the energy performance. Lastly, this case study shows how can be succeeded reduction in energy consumption of a historic building without any modification of the building’s artistic and value of a heritage building. To conclude, the economic analysis taking into account the combined retrofit systems showed a payback period of 5 years and the life spent for implementing this systems is 15 years. It is important to mention, as it influences the study, that in Italy the regulation about heritage buildings is severe and forbids any change to the façade exterior appearance. (Anna Laura Pisello, 2014)

Italy again, except from the LEED rating system, recent years has introduced the CBC Historic Building system which is applicable in historic buildings only. That is because, LEED does not cover affairs related to a sustainable restraint of cultural aspects that a built environment might have. A case study about this system occurred in central Italy, an ancient stable in the complex of Sant’Apollinare Medieval Fortress in Perugia. After the refurbishment the building will be used as an International research center.

The building has 3 floors of 140 m² and the one is underground. The building has a stone structure and wooden floors. There was permitted an external insulation and cement plaster was selected to preserve the ancient configuration. Before the restoration, the energy analysis shown the heating and cooling demands via proper software and the total consumption was measured. The main interventions include the design of high performing envelope and adequate heating, ventilation and air-conditioning (HVAC) plants. To this aim, passive techniques such as high reflective clay tiles were involved. In addition a cool roof was selected with same visual appearance as before. As far as the

whole building is concerned, the total surface was covered also with cool materials to maximize the cooling potential.

As a result, the Solar Reflection Index (SRI) determining the cooling potential of the surface, corresponds now to 67 and the final SRI value of permeable stone natural paving is more than 45. Summing up, this rating system recognized the needs of the estimated building for heating and cooling and processed energy through simulation tools and through interventions energy efficiency enhanced. The experience of the case study of an historic building in central Italy has featured some modernizations and procedures to save energy, advantageous for the development of GBC Historic BuildingTM prerequisites and credits. (Paola Boarina, 2014)

Sometimes only the implementation of a thermal plaster as an insulation can be an excellent solution for the energy performance of a building. This is because thermal plaster is an easy installation and can lead to good compromise between the conservation aspects and energy efficiency. Thermal plaster is very identical to the traditional plaster and can be easily used. With thermal plaster, the thermal transmittance is really improved and sometimes thermal conductivity can reach a reduction of ten times than traditional ones. New thermal plasters are still under investigation in order to reach lower thickness and minimum thermal conductivity.

In Italy, thermal plaster implementation took place in an envelope of a historic building in Turin, built in 1580. The research focused on the thermal properties of a vegetal based plaster. Vegetal based plasters contribute to enhance the insulation and the properties of the plaster help the avoidance of cracking. There were some laboratory measurements to assess the thermal conductivity of these thermal plaster samples, resulting that vegetal aggregates have great capability of reducing thermal conductivity of the plaster. The examined building has an envelope of a brick and stone wall of 500mm thickness, and a 60mm layer of insulation was placed, made of vegetal aggregate materials. The temperature was controlled and the energy balance of the envelope was measured before and after the insulation. As far the measurements results are concerned, the surface temperature was noticed to be lower on the floor and near the windows, due to thermal bridges. In addition the thermal losses were higher than those where the wall had thermal plaster. Finally, the laboratory measurements and the monitoring shown that the thermal conductivity managed to be 3 times less than conventional-existing plaster and leading to reduction of energy losses about 20-40%. (Lorenza Bianco, 2015)

Nowadays, new technologies are available in order to succeed high energy efficiency in buildings. But as far as the worth aged buildings are concerned, these best technologies may lead to conflicts. So for that reason, less performing technologies may be used. But is this effective enough? In the upcoming case study, 2 different refurbishment techniques-best new available technologies and less performing technologies- occurred and compared in a historic building and the results was revealed.

In Italy, again, energy consumption of historic buildings is estimated in high levels but the components and indoor quality make the conditions inside the building tolerated. The aim of this investigation is to compare 2 scenarios respecting the improvement of energy performance with 'Best Available Technology' and with 'Allowed Best Technology'. The selected building is located in the historic area of Ragusa, in the south cost of Sicily, the 'Palazzo Battaglia'. The building has been repaired in 1772 due to an earthquake. It has 3 floors and the main components and elements are tufo stones combined with mortar.

Firstly, the energy performance was calculated taking into account the heat exchange of the opaque and transparent elements of the building and also the heating system which consist of electric heating devices. The building has been separated in different thermal zones and only the ground floor and first floor has been considered in the research. Then the primary energy demand was estimated.

The energy renovation scenarios assumed interventions on the opaque and transparent elements. The best case scenario, allows any intervention which refers to new technologies. A thermal barrier coating was chosen made of EPS (Expanded Polystyrene) with a thickness of 40mm and low thermal conductivity. For the windows, aluminum frame with thermal cutting and single-chamber window with argon was selected. The less effective scenario excludes the coating on the surface because the envelope would change and in this scenario this is not allowed. In that case a plaster, mixed with elements was adopted carrying low thermal conductivity. About the windows the change compared to the first scenario is that there is no aluminum but wood, in order to keep the aesthetic and architecture of the heritage.

The results of these two scenarios vary and have huge interest. The best available scenario allows to succeed really high energy performance and increase the whole energy efficiency in the two floors. Furthermore, the energy demand is considerably lower than in the less effective scenario. The best available technology allows the building change

category and reach A, in spite of the allowed best technology which reaches category B. As a conclusion, both two scenarios allow an improvement in the energy efficiency but they are depending on the level the interventions can be, respecting the historic value to the full extent (Allowed technology) or not (Best technology).

From the economic side, surprisingly the best available intervention is cheaper than the allowed. This is because aluminum frames is considerably cheaper than wooden. Generally, the allowed technology can be more expensive but gives the chance to keep the historic building with its glamour and culture. This case study refers to the legislation of every country and the interventions are affected from stringent regulations or not. Finally, the interferences concern only the building elements and not the HVAC systems, where the results may differ greatly. (Daniele Milone, 2015)

An alluring research took place in Baltic Sea and especially in 3 countries, Estonia, Sweden, and Finland. In comparison with the previous projects the climate now is cold. The survey considers historic rural houses and after visiting 24 houses in Estonia, 20 in Finland and 23 in Sweden, 3 example houses were selected for renovation. Especially, in Estonia there is a historic farmhouse, a barn dwelling. Over the years some changes have been made and in 19th century a chimney was built. The walls are made of natural stone and wooden logs. A log house is the selected building in Finland. Built during 1700-1940, has a shingle traditional roof and the floor's structure is a plank. Finally in Sweden, the dry wall technique was used, meaning that there were sandstone and limestone stones stacked on top of each other and the doors are made of wood. All these 3 buildings have fireplaces and last years were put oil fired boilers.

The renovation of these houses includes 3 aspects. Structure, physical and indoor climate, Energy performance and building service related aspects. The structure aspect concerns the replacement of damaged floors or walls, the physical climate aspect includes improvements in air leakage and additions of heat and ventilation systems and finally the energy performance comes with 3 packages. Firstly only few changes can be done to external surfaces in order to save cultural and historic meaning of the buildings. Secondly, the improvement of thermal comfort is necessary starting with the insulation of the buildings. Finally the third package concludes the enhancement of the energy performance starting with building service systems.

The calculation of the energy consumption and performance take many parameters into consideration, like the number of the inhabitants, the indoor temperature, appliances,

etc. The changes consider insulation in the walls, change of the windows, base floor and ventilation systems. The appearance of the building could have minimal changes when only heating and ventilation systems are improved. As a result, improving these systems and using the best energy source can improve energy performance by 50%. Especially reduction of 46% in Estonia in primary energy, 47% in Finland and 37% in Sweden respectively.

After the analysis of the renovation of the three houses in Baltic Sea the results indicate the dependence of energy savings on energy saving targets, type of the building, and building service systems. Historic buildings require a special approach in addressing energy performance. Nevertheless, owners and inhabitants want to improve the performance in the view of high maintenance costs. Improvement of the building systems (ventilation, heating) seems to be the most ideal solution because does not affect the façade of the building. Finally, the analysis showed that the improvement of building service systems and the energy sources produce the largest energy saving potential. (Üllar Alev, 2014)

Heat energy consumption in old buildings is not highly afflicted by the heated area or the building year of construction. This is shown in the next analysis which focuses on the historic brick building's energy consumption from heating and defines the affection of the element's characteristics on the consumption.

An inquiry of heating energy consumption in historical brick buildings has been done, by associating measured energy consumption data of 171 buildings from AS "Rīgas siltums", in Riga, Latvia. All of these constructions have been built between 1850 and 1940. The total heat energy consumption comprises energy for space heating and energy used for hot water. Taking measurements from 2009 till 2012 the heating energy consumption for these buildings is 181 MWh per year. From estimated results and graphs, specific energy consumption for space heating is not affected neither by the manufacturing year of the building nor by the heated area. There is a modest decline in energy consumption for younger and larger buildings, but the interaction of data is weak. Although, the consumption in historic buildings is lower than the average buildings in Latvia, is high compared to modern constructions and energy efficiency requirements. For that reason, measures should be taken in order to achieve energy efficiency and at the same time preserve the historical value of these buildings. (Kristaps Kass, 2015)

Another example of rehabilitation of historic buildings is multi-family constructions in Belgrade, built before World War I. (Picture 3) In 2011 Serbia started participate more actively in the concept of energy efficiency in the buildings, where also regulations started to enact. The restoration projects started in 2012 respecting the IEE TABULA project through the national project “Energy Efficiency of Buildings—Assessment of Energy Performances of the Serbian Building Stock”, supported by the GIZ (Deutsche Gesellschaft fur Internationale Zusammenarbeit (GIZ) GmbH). The principle was clear, methods to enhance energy efficiency and standard methods to improve energy performance. The first and most important step refers to interventions on the building envelope, like the change of the windows with new one which consistent with the new law and insulation materials along the walls and floor. The main target of the proposed measures were the enhancement of energy performance at least one energy class.



Picture 3: *The houses chosen for restoration in Belgrade.*

The existing elements of the houses were brick masonry as the dominant type of massive wall construction those years, the floor as well as the roof constructions were wooden, and finally the windows were wooden, having double frame, with single glazed sash. The first measurements included only the replacement of the windows and the second interventions added insulation materials in order to reduce heat losses.

In detail, in the walls was put internal 10cm thermal insulation and 5cm layer of insulation in walls attached to unconditioned spaces. Below roof there was an additional 15 cm of thermal insulation, while floor to unheated basement required addition of 15 cm insulating layer. The windows had been replaced by uPVC windows of six chamber profiles, glazed with triple low-E glass unit.

The results vary from the one version to the other. Having restored the windows the thermal losses have been cut about 15% and the heating demand has been limited considerably. The new energy class was now “F” from “G”, one energy class higher. In the second version, having also put insulation layers the distribution of thermal losses through the building was more balanced. The heat losses were reduced 4 times compared to original building and the energy demand reduced more than the half. Therefore, the energy class reached level “D” from “G”. Summing up, bearing in mind that we talk about historic buildings when the energy efficiency of such buildings is concerned, the selection of materials does not refer only in the energy performance necessity but in the first role it should be conformity with the authenticity. (Ljiljana Đukanovic, 2015)

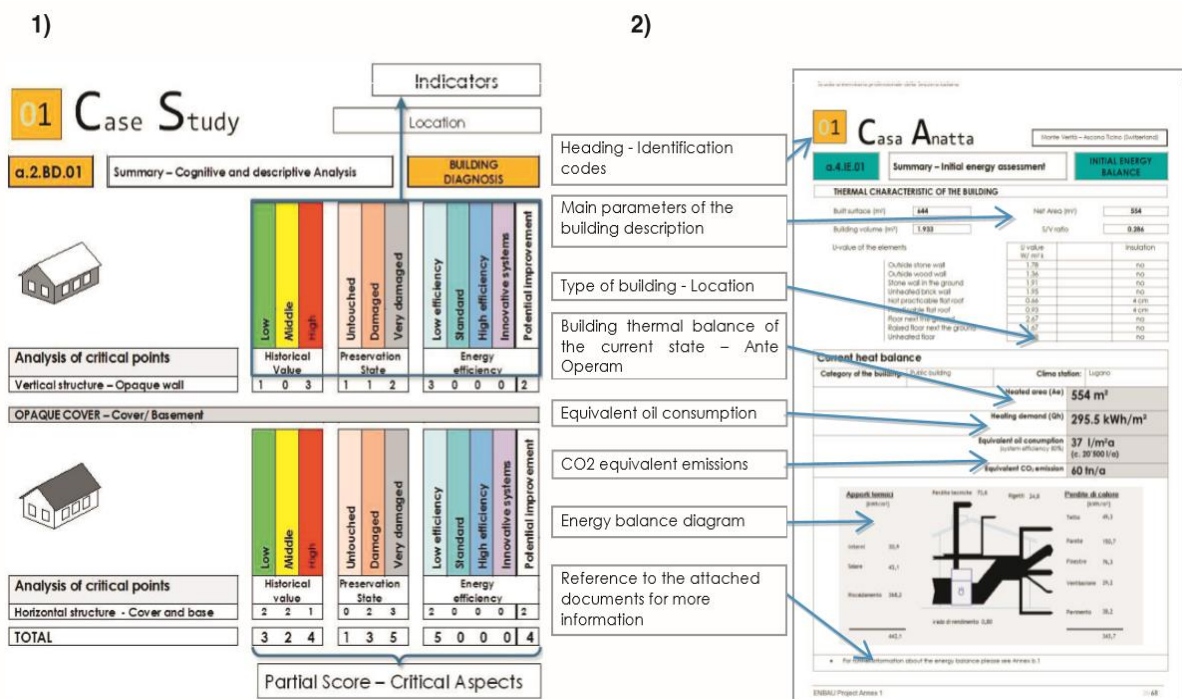
2.3 Penetration of RES in the energy efficiency of historic buildings.

Renewable energy can play a considerable role in a restoration of a heritage historic building and the main scope is the protection of the historic culture and in the same time the implementation of RES. ENBAU “Energie und Baudenkmal” research project have been introduced by Stiftung zur Förderung der Denkmalpflege (Foundation for the Promotion of the Conservation of Historical Monuments) aims to reduce the energy requirements and penetrate renewable energy systems, especially solar systems. This may happen by raising energy efficiency through urban development. The final objective is that, it will be achievable to select a restoration project with a high level of sustainability to assure and advance the level of comfort securing a high-quality and cost-ambitious construction process.

Representing ENBAU research project, there was 3 case studies in Switzerland. These three case studies -Anatta House, Monte Verità Ascona, (1904); Manetti House, Bironico, Monte Ceneri, (1600); Hôtel de La Sage, Avolène, Vallese, (1890)- provided the chance to implement the proposed methodology to occasions with different lineaments and problems, and, in particular, with changeable levels of freedom in terms of admissible solutions. Protection demands and energy savings requirements must be fulfilled but also comply with harmony, with a view to environmental continual and a cautious use of energy resources, in order to improve energy efficiency.

The activities are organized in three steps. Firstly there is a diagnosis of the building’s situation and energy balance. Secondly, there are the proposals for the development of

energy efficiency meaning that there are energy renovation measures and tools to improve energy performance. Finally, the assessment of the restoration plan takes place and there are some thoughts for maintenance. In every step, some parameters should be taken into account. The value and the culture of the construction, architectural features, climate conditions and HVAC systems. Moreover, the integration of solar energy resources predominates. All these aspects and steps provide results in order to succeed reduction in energy consumption, and the final energy consumption is compared to the initial one. This method can operate depending on the significance of the building, characterized as high, medium or low.

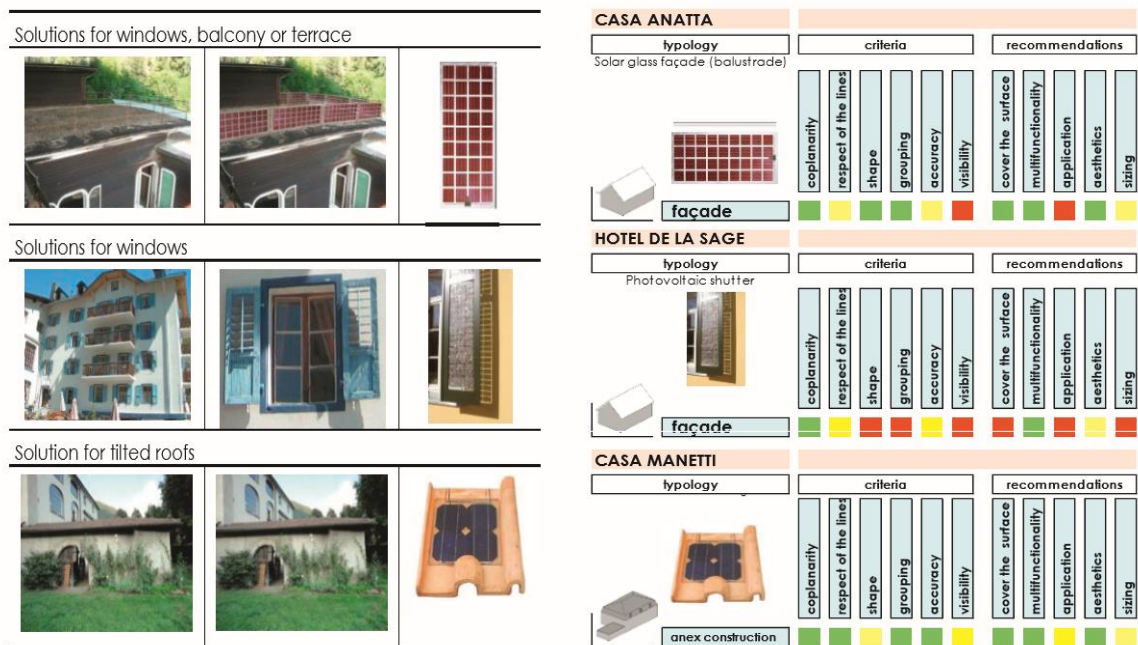


Picture 4: Example of the charts developed during project implementation, first step: Cognitive Analysis, second step: Energy balance analysis chart for setting the current situation of the building.

The used colors are the green, yellow and red. Each energy efficiency restoration measure is categorized according to an established color code as the figure above shows (Picture 4). Symbols are used to identify the involved areas and indicators to assess energetically refurbishment measures in relation to each historical building. Finally the scoring system aims to evaluate these key parameters.

Now, the solar energy systems like photovoltaics and solar thermal should be designed carefully and not impulsively searching the cheapest and more effective solution. (Picture 4) For the implementation of RES every building must fulfil some criteria like

year of construction, architectural quality and elements-materials. ENBAU project respects the historical value and assess when renewable sources can be adopted. Aesthetic requirements and balance are estimated in order solar systems be used. Integrating renewable technologies into an urban background, or into existing structures, can upgrade the architectural and technical character of the building in terms of economic and environmental sustainability.



Picture 5: Example for solar energy solutions in the case studies which examined.

The methodology which analyzed before, considers an energy concept, taking into account the uniqueness of every construction and decisions made to enhance the energy performance of historic buildings. Moreover, it emphasizes the fact that small interventions may bear significant results. The project also helps to evaluate the integration of solar components. (Cristina S. Polo López, 2014)

The next case study houses in Genoa, Italy. Albergo dei Poveri is indeed peculiar because it is huge and old. A feasibility study shows up, and a process for energy efficiency and production is submitted. In addition, renewable sources play a key role in the refurbishment. Nowadays, only the 30% of the building can be studied and lead to results so the study focuses only there.

The study has been organized into 4 steps in order to reach energy performance improvement. The first step includes the analysis of the location of the building. The con-

struction' site is between new and old city systems, in an area with water presence and fresh air. The building finished in 1832 with a total area of 60.000m². After a reconstruction the roof consists of reinforced concrete and bricks and the ceiling is made of wood. To continue with, in step two, energy demand and audit identification are analyzed. The properties of the external walls, windows, roof and floor are clearly determined and the U-values of the elements are calculated. Moreover, the energy consumption is counted, either for the area with fan coils systems for heating or for the area with HVAC systems for cooling and heating. In the third step, the possible interventions for energy efficiency are presented. These changes concentrate on the building's envelope structures. The thermal behavior can appear improvement by insulating the roof, the ground, and the walls. The windows also can be changed but this should be carefully approached. From these changes and interventions the energy saving would be considerable and the energy needs much lower. In the next table (Picture 6) one can see the reduction in thermal losses of the building after the restoration.

Type of enhancement/refurbishment operation	Energy saving [%]
Roof insulation	5
Restoration of external windows (single glass)	6
Substitution of external windows with new certified elements	28
Restoration of windows and addition of a new certified window	28
Restoration of external windows (single glass) and insulation of the roof	11
Substitution of external windows and insulation of the roof	32
Restoration of windows (single glass), addition of new certified windows and insulation of the roof	32

Picture 6: *Energy saving after the refurbishment.*

In step four, there are presented some proposals about efficient energy generation from renewable sources. Solar collectors will give hot water in the building and LED systems for the lighting will reduce the electric needs by 50%. Micro-turbines systems fueled with natural gas are designed related to the energy demand. Micro turbine systems also with Combined Heat and Power systems will contribute for excess electricity generation and hot water. The benefits of those intervention have double meaning. Reduction of the energy consumption but also reduction of the carbon emissions. Finally,

this feasibility study checks carefully the upcoming interventions and discusses about other possible intervention, but which will not adversely affect the historical significance and the building's façade. (Giovanna Franco, 2015)

2.4 CO₂ Reduction in historic buildings

Restoration concerns sometimes not only the limitation of the energy use but also the reduction of CO₂ emissions. This aspect wants to cover the next case study, occurred in Bath, England.

By 2020 carbon emissions must be cut by 30% and in UK this percentage is tougher, putting the limit at 80% until 2050. The target of this study is to evaluate how retrofit adaptations can change the energy use and the CO₂ emissions. Three historic buildings in Bath, England will be studied. Firstly, energy use data was collected and evaluated, gas and electricity energy use data was also collected and then the measures for reduction in energy use and carbons were estimated for the renovation. The research concentrated on the Passive House Planning Package (PHPP) a tool designed to model the performance of 'Passivhaus' buildings. It is used mainly for the retrofit of existing buildings and its heating energy use. With this tool, potential reductions in energy use and emissions will arise from the restoration adaptations.

To start with, the 3 buildings are the one next to the other and the year of construction is 1810. (Picture 7)



Picture 7: *The examined buildings*

There were 3 retrofit packages, aiming the reduction of energy use and carbon emissions. The first package includes low cost interventions with the underfloor insulation, increase roof insulation, central heating boiler, central heating pump, replacing the windows and more. The second package focuses on the external walls. Internal wall insulation was putted in order to reduce energy consumption. The external insulation of the walls was avoided due to aesthetic reasons. Finally, the third package introduced photovoltaic and solar hot water systems in consideration of carbon emissions reduction. The results vary. For the first dwelling, the reduction in energy use was about 74% and CO₂ emission about 64%. In the second case study the delivered energy was limited by 54% and carbon emissions by 55%. The highest reduction is notices in the third building with a reduction of 85% and 83% respectively. To conclude, cutting CO₂ emissions by 50% is possible only by putting insulation materials in the buildings. This work emphasizes in the reduction on energy use and emissions with key the realistic heating pattern. (Francis Moran, 2014)

2.5 Interventions in Historic building in Greece

In Greece, finally, an interesting approach occurred in 2006, the Laboratory of Heat transfer and Environmental Engineering studied the White Tower of Thessaloniki, in duty of the Museum of Byzantine Culture who decided to convert it. The main target of the research was the satisfying thermal comfort and indoor air quality inside the building. White tower is estimated to be built in 1536 and a restoration went on 1983. The building works as museum. It has 5 floors and a ground floor. The walls are made of solid stones. In the beginning, the floors and the roof were constructed of wood and presently are covered with lightly armed concrete and concrete with ceramic tiles respectively.

Due to the importance of the building, before any intervention, some facts must be clearly defined. Firstly the energy needs of the building have to be fulfilled. Then the visual result of the interferences has to be non-existent and as far as the energy consumption concerns, should be kept on low level. The structure and the type of the building limit the opportunities for vertical ventilation, due to the fact also that the existing windows are too small. For that reason in 1983's restoration new piping and air ducts were installed.

The methodology which was approached has to deal with some facts and the most important was the loads generated by the visitors. So the stages were three. Firstly, there was the monitoring and evaluation of the indoor air quality and secondly what effects do the visitors and the devices lead. After those simulations possible interventions took place and the impacts of them calculated.

To begin with the initial measurements included the CO₂ concentrations measured with CO₂ sensors, indoor temperature and relative humidity, the airflow field and the infiltration rate of the internal area and the surface temperatures with IR FlexCam infrared camera. The research, separated in 2 periods, the cooling period and the heating period. The results of the CO₂ concentrations related with the acceptable limits and for the estimation of the indoor quality the building was separated in 12 thermal zones, 2 in each floor. In order to control the airflow, there were some restrictions concerning the number of people in every floor and the mechanical ventilation was changing frequently.

The results of this study are represented by two days of the year, the worst days of summer and winter. The white tower have high thermal storage, so there are no fluctua-

tions in the indoor air temperature. The humidity is not in sufficient levels (54%) and the surface temperature remains high throughout the day. As a conclusion, the major problem and concern was noticed in the dehumidification.

For the CO₂ concentrations, some experiments took place, including measurements with specific number of visitors into the museum and for specific time. The results showed that the concentrations exceed the acceptable limit so the ventilation of the place becomes insufficient. To reach acceptable limits the space should be empty for 40 minutes.

After all these, the recommended interventions concern the installation of window fans in one embrasure per floor with target the control and increase of the ventilation. The historic meaning and architectural restrictions of the building did not allow a HVAC system. The solution came up with the installation of portable dehumidifiers in order to control the relative humidity. Finally, in the ground floor, the door remains open throughout the day so an air-heating curtain was preferred to control the comfort conditions. (A.M. Papadopoulos, 2008)

3 Regulatory point of view in Europe and Greece

As we saw in the literature review, the energy consumption in Europe depends on the buildings in crucial degree. Consequently, EU recent years established directives with main scope the energy efficiency and backfit of the buildings. Respecting the historic buildings, these directives, do not bring about these constructions and in national level omissions could be made to exclude them from the interventions in buildings. For that reason, every country of EU can admit its rules and standards to deed these buildings or not, in energy use balance.

In detail, the EU directives, concerning the energy use and consumption of constructions generally, are two. Directive 2002/91/EC and Directive 2010/31/EU. The first is the older one and includes mainly new buildings but the second one refers to actual buildings concentrating on renovation projects and the time when building elements and systems are reinstated. The second Directive suggested chiefly because last years, European Union deals with a big crisis in the construction sector, which has affected considerably the economic sector of EU countries. (Parliament, L 1/65,2003 04.1)

3.1 What include the Energy efficiency regulations?

The two directives we mentioned before, have as major target the reduction of the energy consumption, which the last years has increased dramatically.

In the 1st directive, article 4 mentions that Members have the right not to apply if they have requirements for the following categories:

1. Buildings protected for their historic importance or as part of a designated environment, where compliance with the requirements would unacceptably change their character or appearance.
2. Buildings use for religious activities or worship.

In 2nd Directive, article 4 again, emphasizes that constructions with heritage Culture in so far compliance with certain minimum performance requirements would unacceptably alter their character or appearance.

Finally, a new directive introduced in 2012, the 2012/27/EU regarding the energy efficiency. We should not forget and pass by the fact that every country has the right to make alterations which consider to be admissible and do not give away the historic significance. (Parliament, L 153/13, 18.6.2010.)

3.2 Legislation in Greece respecting historic buildings

The major law which refers and is compatible with the EU directives is the Law 3661/2008 (Government Gazette 89 / A / 2010) which deals with measures to reduce energy consumption in buildings and other provisions. The provisions of this law, harmony the Greek legislation with Directive 2002/91 / EC European Parliament and of the Council of 16 December 2002 "For the energy performance of buildings ".

Specifically about the historic buildings, in the scope of this law the following categories of buildings may not be covered:

- a) Buildings and monuments protected by the Act as part of a designated environment or because of their special architectural or historic merit, where compliance with the requirements of this law would change in a way unacceptable, the character or appearance.
- b) Buildings used as places of worship religious activities. (Republic, 19 May 2008)

3.3 Historical information

In worldwide meaning, regulation respecting the Architectural heritage is UNESCO's Convention touching the conservation of the World cultural and natural heritage. (UNESCO, November 16, 1972) This legislation is really solid and the main reason is that historic buildings recent years are intimidated with destruction.

In Europe, the protection of buildings with historical meaning began with the "Convention for the Protection of the Architectural Heritage of Europe". (Europe, October 3, 1985.), Enters maintenance principles, follows the interpretation of EU standards of

protection for important Architectural Heritage and introduces legal commitment that has to be implemented.

3.4 Discrimination between historic-historical-contemporary buildings

Historical buildings present something from the past, concentrating on the age only. For that reason, most historical constructions have negligible historical meaning, or not at all. The contrast is covered by historic buildings, which are also really old but emphasize on the meaning, the affection and the importance of the building. Correlating these two, historical may refer to the past but may not have any historical significance and historic is important by definition.

Laws protect historic buildings and no interventions can be done without specific permission from the local and national authorities. Historical structures, so, have no insurance by default. Usually, a defenseless procedure is followed to possibly get the status of historic building.

Historic buildings specifically are characterized by 3 things: age, historical significance and high degree of physical integrity. In detail,

- *Age* means old enough, older than 50 years. Refers to buildings that have been examined by architects, historians or archeologists and carry a clear place in history. However some buildings relatively newer (under 50 years) with also clear history should be acknowledged as historic.
- *Integrity* means to hold on its historic and mental physical purity. Architecture, landscape aspect, historic location and commune which should not go through any change. Accordingly, the location must be undisturbed and absolutely definite to today's connected cultural body (traditional cultural property)
- *Significance* refers to buildings which should be significant to consider historic. Importance means Blunt Corporation with individuals, actions, activities or interventions that framed our history or mirrored attitudes of our history. Moreover, demonstrating original, physical and spatial aspects of architectural style or type of construction design. Summing up, having potential to extract information considerable for our knowledge and understanding of the past through architectural analysis. (Mazzarella, 2015)

4 Refurbishment techniques of listed Buildings

As we have already seen and emphasized, historic building stocks are considerably different from the residential or new buildings. This fact is noticed clearly in the consumption. For instance, energy loss through air infiltration indicates a significant percentage of the total losses and this may be higher in houses with many gaps, like windows and doors. For that reason, the control of air-infiltration is the first step to take into account for upgrading energy performance of older buildings. Large amounts of energy are possible to be lost during the construction through gaps. To manage the air-infiltration someone can repair cracks and holes in the building, install draught-stripping to windows or replace windows with new one which have air-infiltration standards at a modest cost. Finally, installing a secondary glazing can also help to restrict heat losses effectively.

Generally now, in order to reduce energy losses and make the building more sustainable we have to implement some interventions. In historic buildings, due to the age and maybe the tough regulations only one specific and single action could enhance greatly the performance of the construction and reduce the losses. However, someone should be careful and cautious because a combination of interventions could lead to adverse effects. For example, the conversion of the old lamps fluorescent fixtures with electronic ballasts would curtail the consumption for lighting or air-condition demand but would increase the demand for heating in the winter, as the new lamps do not emit heat.

After studying carefully case studies of listed buildings, the possible mediations vary and depend on every occasion and on every building separately. In Mediterranean and hot climates the changes are different than in cold climates. The most common activities and changes are noticed in the restoring or replacing the single-glazed windows or supplementing them with storm windows and the internal insulation of the walls. Another substantial factor is the lighting upgrades and the control of them plays important role. Finally the heating system participates strongly, as upgrades of old ones are necessary.

In detail, the interventions could be characterized as primary and secondary. The first one can contribute strongly to the energy performance and the other can enrich and complement the succeeded energy efficiency of a building. In primary retrofits partici-

pate the insulation of the roof and the walls, the HVAC tubes, the radiant barrier and the ventilation.

Roof insulation is adequate at preserving energy. Roofs are reachable and any change does not disturb the historic view. The addition of batt insulation or blown cellulose without vapor boundary is a solution. In hot climates, radiant barriers are usual and the main reason is the capability at cutting down the solar heat gain. Radiant barrier is a contemplative, malleable material which is easily applied to the underside of a roof. The internal insulation is more essential than the external insulation. External insulation practically affects the appearance and this could remove the glamor and meaning of the building.

HVAC ducts aim to reduce air leakage and are necessary as they can limit the losses of HVAC systems over 25%. These tubes are applicable into the attic. Moisture is a major problem in historic buildings, especially in climates where the winters are wet. Due to the age, a historic building should breathe more. The high levels of moisture do not give the opportunity for this and contributes to considerable issues. Unoccupied attics need ventilation in order to restrict moisture and also in order to preserve the life of the roof.

As secondary interventions we can include the air filtration and the floor insulation. The air infiltration gains come from the windows and doors mainly. In wooden frames there are gaps and so should be included in the retrofit project. Useful and effective methods are the paint and the caulk systems. The installation of weather-stripping around doors and windows is essential also.

The windows enact seriously in the performance of a building. In historic houses, however, the windows cannot change their exterior appearance because the historic value should be maintained. The performance gain to be accomplished from changing half the windows is imperceptible compared to weather-stripping the historic windows. The energy efficiency is succeeded primarily from the lower infiltration rate. As far as the floor is concerned, between or under the floor joists insulation could be placed. The best option seems to be the rigid foam board insulation. (William Dupont, September 2013)

4.1 Methods of interventions

In Nis, Villa Zivkovic in Niška Banja is an illustrative example of historic construction with modern architecture. The renovation proposal was allocated into several methods. The first one is the planning of new infrastructures into the existing building, in order to emphasize the contrast between the 'new' and the 'old'. The new constructions obviously keep the architectural heritage and significance. Secondly follows the interventions in existing structures on the interior space on the pillar of historic meaning. Last but not least, the combination of the previous methods is also a choice.

Taking into account the first method, a new sector in an existing building must obey the rules of the adaption combined with the contrast and partition of the new to the old. This may be succeeded with the method of realization. For example the expansion of the building or the separation of one space to two etc. The reactivation of architectural entities with target new ways of management is legitimate if this interventions do not disturb the structure or the character of the whole building. (Milja Penića, 2015)

3ENCULT is a project which was completed in 2014. The major aim of the project was to verify proposals and solutions which are applicable to the majority of European old historic buildings in urban areas. Some of the proposed interventions are presented next:

- 1) Insulation
- 2) Enhanced, compatible windows with heritage
- 3) New lighting
- 4) Ventilation systems
- 5) Solar intergration

Another project in which Greece is also involved is RESSEEPE which started in 2013. The main target of this activity is innovative retrofit measures to achieve 50% reduction in energy consumption. The technologies and the materials which are used to reach the goal and participate in the retrofitting are:

- 1) Envelope modification: aerogel-based Superinsulating mortar, wooden insulating wall panel.

- 2) Intergration of RES: PV systems and thermal collectors
- 3) Energy systems for storage: nanotechnologies and smart materials
- 4) Smart building controls like HVAC systems.

4.2 RES as an important method of restoration

As it was indicated before many times, RES play important role to succeed energy efficiency and also to reduce CO₂ emissions. For that reason techniques and methods including renewable sources are famous and are used many times in renovation projects.

A project which finished in 2010, the NEW4OLD, with the participation also of the National and Kapodistrian University of Athens, Greece is an indicative example. The goal of this project was to refurbish a historic building located in Brussels as well as to create a network of 'light-house renewable energy houses which would be under discussion of all EU members. This building tends to be an amazing case study for the penetration of renewable energy in old historic constructions. The objectives were clear, covering of energy demand only with RES and reduction of energy need for HVAC by 50%. (Esteban Vieitesa, 2015)

The energy efficiency accomplished with the following measures:

- 1) Insulation of façade and roof with 15 cm of Expanded Polystyrene and 15cm mineral wool respectively.
- 2) Replacement of the windows with new sun defensive windows with Uvalue of 1, 5 W/m²K.
- 3) Heat recovery wheel and ventilation system controls for the enhancement of the mechanical ventilation.
- 4) Heating system with pellets including biomass boilers and Stirling engine.
- 5) Geothermal energy loops and a grounded heat pump.
- 6) For electricity PV systems were installed.

5 Case study: The project of a listed building in Ladadika, Thessaloniki

In this chapter of the study, a case study will be analyzed and presented. Initially a brief description of the area will be cited to show the origin of the building and its history. To continue with, the action of plan will be displayed and the existing situation as well as the proposed interventions will be stressed. Finally the results will be summarized in order to find what affection had the alterations and the retrofit in the building, from the energy performance point of view.

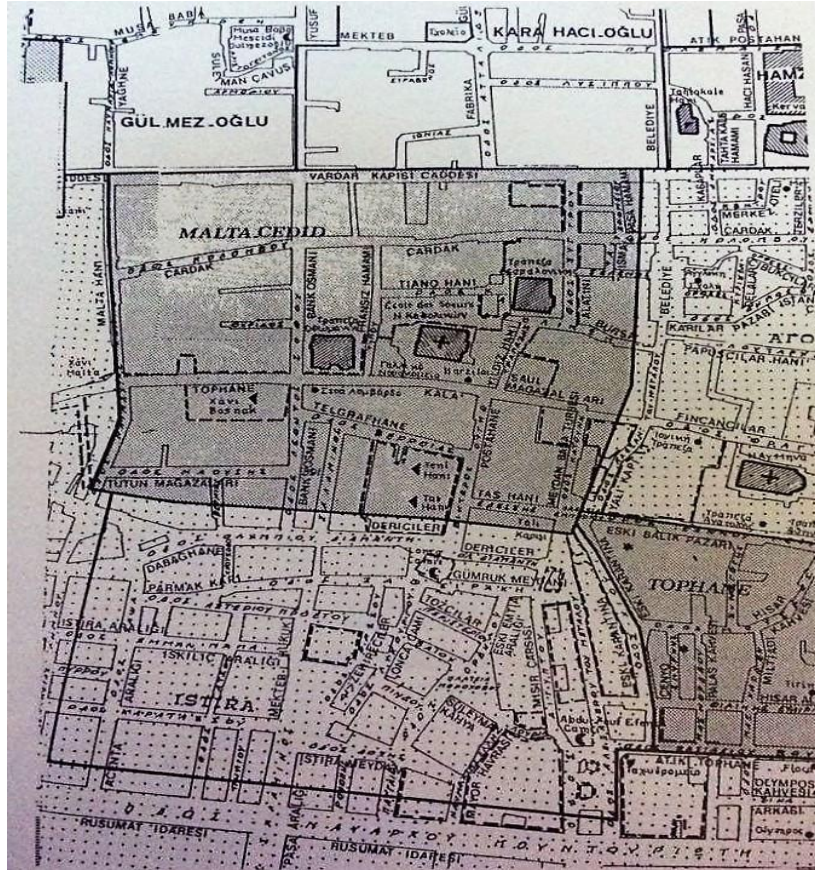
5.1 Ladadika: A landmark area of Thessaloniki, Greece

Thessaloniki is a city with a history over 2300 years. This leads in obvious that there are many archeological pieces pf evidence. However, debris and buildings in the main urban web show also the history of Thessaloniki. Some of these regions are Ladadika, Upper town, and some areas in West and East Thessaloniki.

Heeding the most commercial street of Thessaloniki Tsimiski Avenue, immediately after the Freedom Square someone will meet the famous Ladadika. A beautiful historic area, specially equipped only for pedestrians, which is a favorite destination for both locals and visitors and for city unique student community.

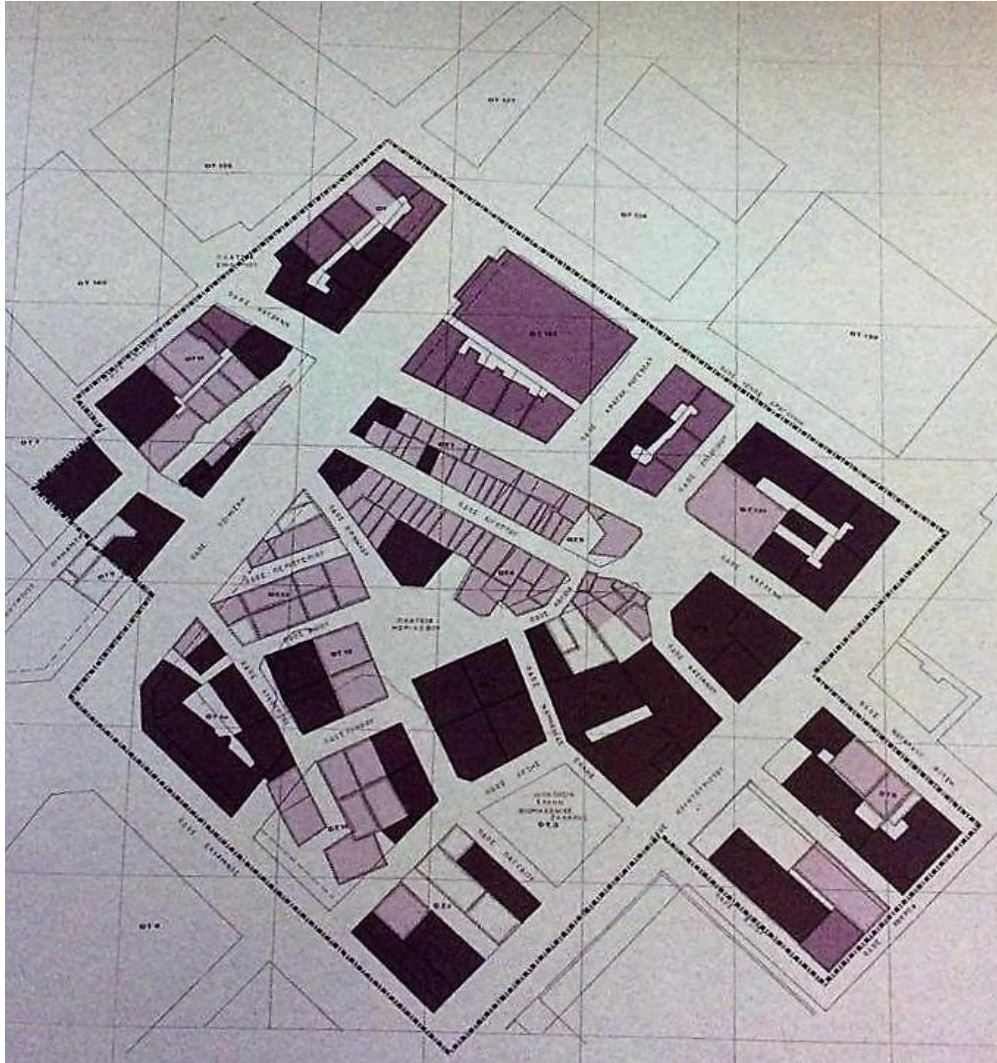
Ladadika is a historic district and is located near the port of Thessaloniki. The name “Ladadika” emanates from the shops that existed in the region much earlier and old oil and various oil products. The whole area was used as the central market and bazaar during the Ottoman rule (Picture 1Picture 8) and earlier and in 1866 when the railway network constructed there was a commerce flourishing in the area. In addition, Ladadika area was the meeting point with foreign people and cultures. It entertained a lot of

shops and tradesmen with abundance of products, however after the liberation, the slum region of the older bazaars of the Turkish occupation fell into decline. Along some narrow streets decadence had touched the bottom and housed ill-famed actions, going back as in World War I times.



Picture 8: *Ladadika region during the Turkish occupation.*

In 1917, a destructive fire destroyed the majority of the buildings in the area and the stores began to decline gradually, so after a few decades the only shops left were those that supplied oil. By the mid-70s the area was almost abandoned, when in 1985 was proclaimed preservable by the Ministry of Culture, thus prohibiting further rebuild in order to preserve the unique architectural heritage and nature. After the earthquake of 1978, the gradual abandonment of dilapidated buildings began and the area started to decline. In 1985 the district was declared as a “historical place” or characterizing structures as to “be preserved” by the 4th Inspectorate of modern Monuments of the Ministry of Culture (Picture 9) and in 1990 came in a redevelopment program with in charge engineer architects Miltos Mavromatis and Kostas Loizos. (Miltos Mavromatis, 1996)



Picture 9: Inventory of the buildings. With light purple are those built before 1917 and dark purple those after 1950

5.1.1 The plan of action

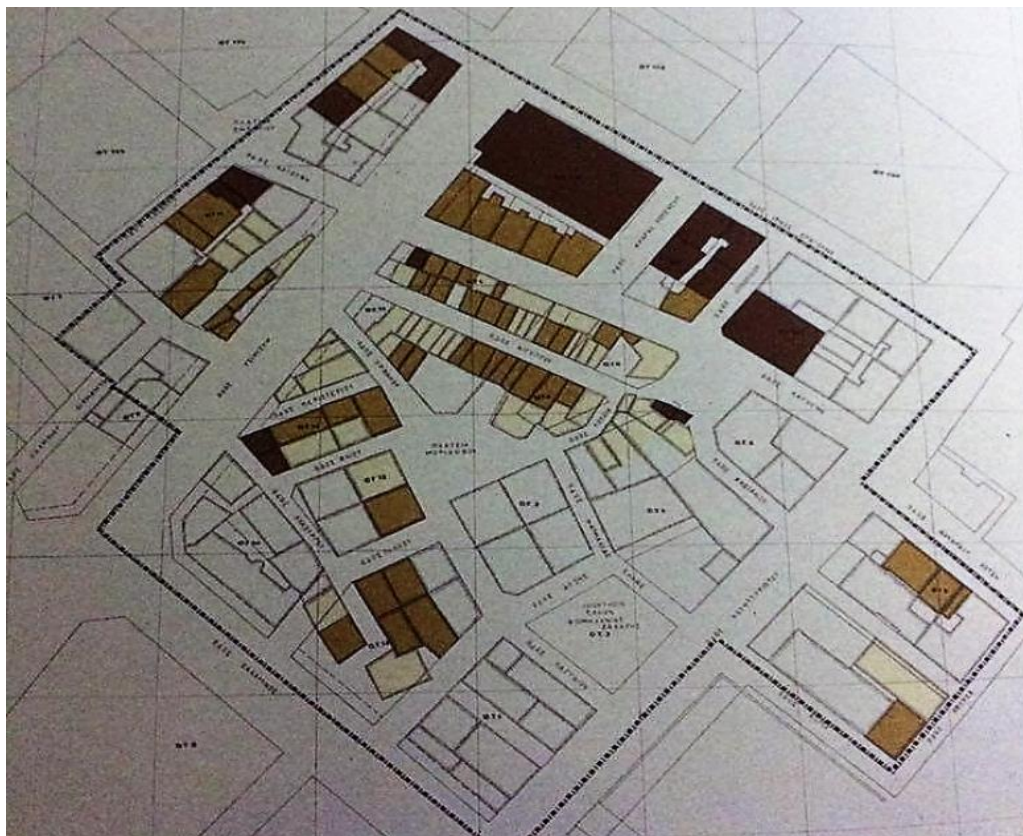
The venture into another preservation policy was not easy. The final plan of activity targeted at the rescuing of the buildings, participation of the citizens in preserving the structures and the repair and use of those destroyed buildings. Moreover, it was necessary a gradual increase of the value of the architecture to discourage the case of exchange of built-up surface. Finally, the revitalization of the inaccessible historical center to the citizens as also the economic increase were in the program. (Miltos Mavromatis, 1996)

As far as the buildings concerns, the implementation of the interventions was not also easy. The restoration of the buildings included only points which would not disturb the

authenticity and the historical meaning of the constructions. For that reason the principles were chiefly based on the English and Italia School and the main points are the following:

- Restoration of the covering shell with the use of iron for static reinforcement of wooden structure and armed concrete on the foundations and on roof.
- Conservancy of the authentic and unique morphological elements of the facades.
- Fixing and upgrading of the composition of the supporting walls.
- Preservation and spectacle of tracks of decorative elements of supporting walls.
- Internal arrangement of the building, including roof repair, color restoration and maintenance on morphological-decorative elements.

After this difficult venture, last century's building complexes, carrying the name "Ladadika", have been rescued. 43 buildings, which survived the 1917 Great Fire, stand on their foundation today and are only one example of these results. (Picture 10)



Picture 10: *The situation of the buildings before the intervention. With purple are the buildings found in good condition and with orange those in moderate to good condition. The white buildings found in bad condition.*

5.1.2 The legislative protection framework

The Minister of Macedonia and Thrace signed the pertinent resolution which was published in the official Gazette No1217 D/22.11.1994 with the title “Designation to be preserved of 87 buildings at the historical sight ‘Ladadika’ of Thessaloniki and imposition of a special regulation for protection – restrictions and uses.”

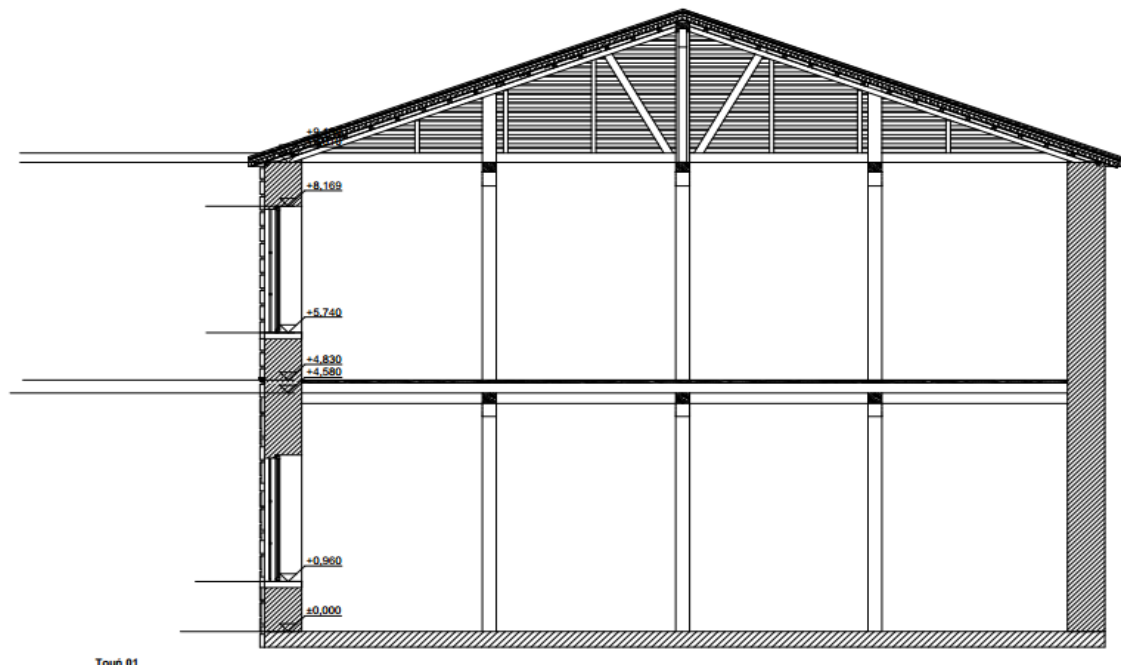
Technical chamber of Greece, section of central Macedonia presented the “Listed Buildings and Elements of Human Induced Environment -Traditional Settlements and Housing Totals - Historic Centers and Cities” which examines the legal framework governing listed buildings and the procedure and characterization of a building criteria as preserved. Specifically, the content is analyzed mainly of Laws 3028/2002 (HMC) and 2831/2000 (Ministry of Environment), where the provisions referred to the historic buildings and how to maintain them. The procedure for designation as a listed building is described in detail and the key criteria are given. This presentation also describes the procedure for monitoring corresponding studies and their contents. Finally, it gives the incentives that the state should provide to the individual in order to promote the preservation and not the destruction of architectural heritage and the elements of human environment. (Technical chamber of Greece, 1996)

5.2 Description of the examined building

Some of the methods displayed earlier were tested in a case study and helped us fill in the blanks. The object was a building in Ladadika, a warehouse from the 1890s, and the most important fact which we should mention and emphasize is that this building is characterized as listed because survived after the great fire of 1917.(Picture 11) Nowadays the building is not used and this can affect the current situation of the elements.

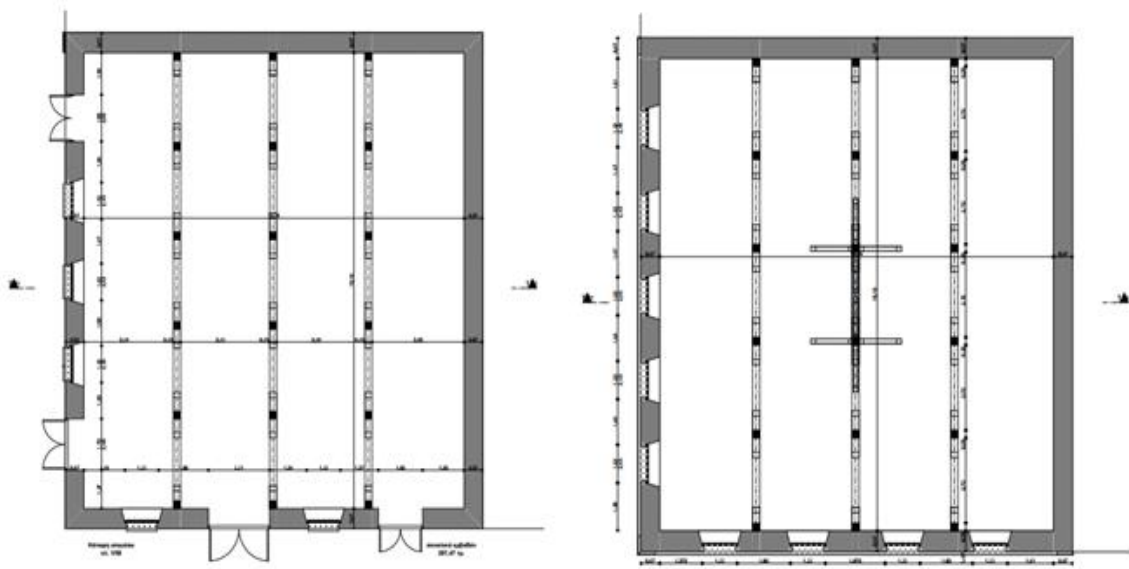


Picture 11: *The examined building in Ladadika, Pindou 9 Street.*



Picture 12: *The incision of the examined building.*

The total area of the place is 415m². There are 2 floors, totally symmetrical and open-plan, practically without interior walls. (Picture 13)



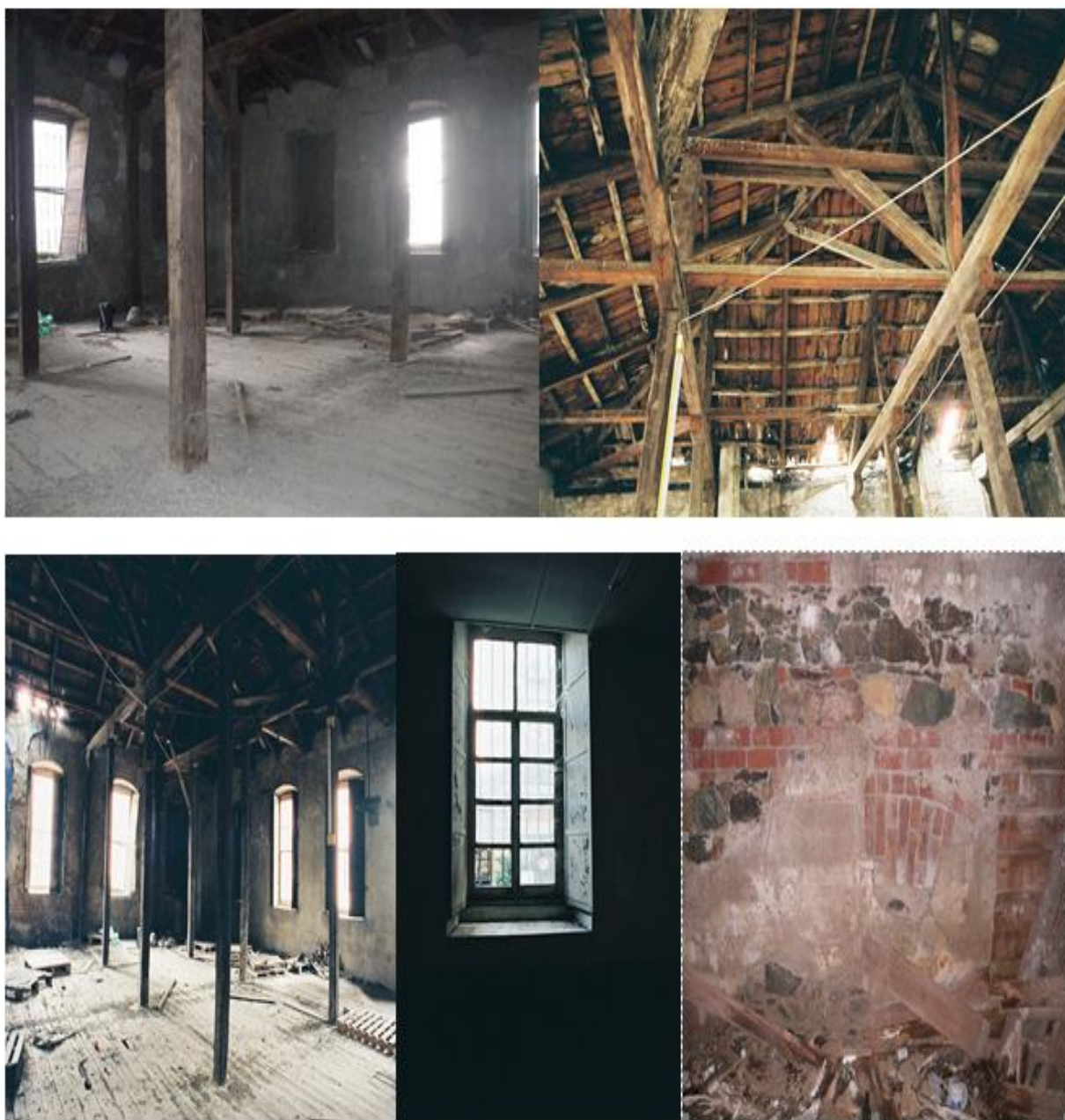
Picture 13: *Plan of the 1st floor (left) and the 2nd floor (right) of the building in Ladadika.*

The construction is characterized by the number of the openings which reach the number of 18. The windows are also relatively large, one glazed windows with metallic frame and without thermal break. In addition, the existing doors are also metallic. The floor is wooden, adjusted to the ground and the roof is an area of plain tiling upon wooden ceiling. As far as the walls are concerned, in the first floor the main material is rough fragments of stone coated from both sides. The main reason for these elements is to ensure that the building would be solidly attached and stable. The walls of the second floor consist of double bivalve bricklaying. (Picture 14)

In detail, the U-values of the existing elements on the building are:

- $U_{\text{Roof}}: 4.25 \text{ W/m}^2\text{K}$
- $U_{\text{floor}}: 0.49 \text{ W/m}^2\text{K}$
- $U_{\text{walls with stone}}: 3.85 \text{ W/m}^2\text{K}$
- $U_{\text{walls with brick}}: 2.20 \text{ W/m}^2\text{K}$
- $U_{\text{windows}}: 6.1 \text{ W/m}^2\text{K}$
- $U_{\text{doors}}: 6 \text{ W/m}^2\text{K}$

The building has a central heating with oil boiler and itself has not displayed any signs of mold issues, possibly due to the big number of the openings. Finally the installed power for the lighting is 6.64kW when the natural lighting reaches the 65%.



Picture 14: *The internal space of the building and the existing elements.*

5.3 Proposed interventions

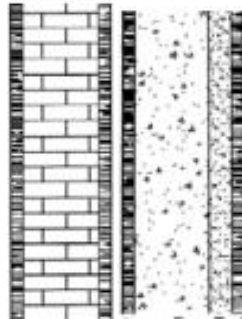
In the sector above we have presented the existing situation of the building and we can notice, before we give results, that the current elements and systems cannot be adequate. For that reason, some interventions and changes were designed and analyzed. We should not draw a blank to the fact that our examined building is a historic building and demands particular concern. The building is also suggested to be a grocery or a shop generally so the approach takes into consideration this fact. To begin with, the action plan consist of the following interferences which will be further analyzed.

- Internal insulation
- Roof insulation
- Alteration of the transparent elements
- HVAC systems
- Lighting

5.3.1 Insulation of the walls and the roof

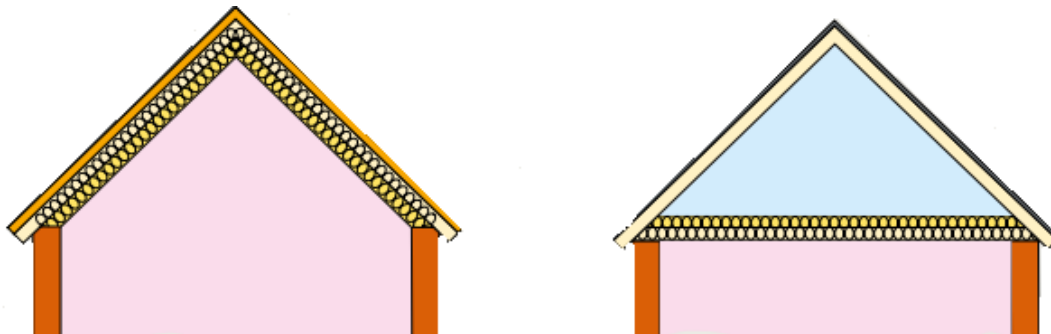
The first step in order to reduce the consumption and the energy losses is mainly the insulation. In a common building the most usual intervention is the external insulation. But as mentioned before, listed buildings most times cannot change their appearance not in the slightness so the internal insulation seems to be the most proper choice. Earlier we stressed that internal insulation sometimes can cause moisture problems on the walls and erosion but in our case is the most suitable solution in the mean of economic view and also because moisture is noticed to reach low levels in the building. In addition and more specifically, insulation will be put on the walls and on the roof. Obviously the material will be put only on the walls exposed to external air. Seeing that, the selected element is XPS - Extruded polystyrene, a lightweight, heat insulation material based on polystyrene. A key feature is the enclosed

pores and the lack of water absorption, which make the extruded polystyrene suitable for applications in high humidity. The thickness of the XPS in our case is 3cm and the Thermal Conductivity (λ) is 0,03 W/mK. Finally, the new U-value of the wall will reach the 0,614 W/m²K. (Picture 15)



Picture 15: *The wall without insulation and on the right the wall with an insulation material.*

As far as the roof is concern, the quandary was great. The roof is pitched and covered with tiles, meaning that the insulation could be designed in 2 ways. (Picture 16) The first technique includes insulation at the level of the horizontal ceiling of the topmost floor, leaving an unheated roof area, like a loft above the insulation. On the Contrary, the second method has insulation between or over or under the sloping rafters, in order the total volume under the roof be heated and used. (Ogley, 2010)



Picture 16: *The 2 techniques of roof insulation. (Ogley, 2010)*

For the examined building, the most proper method is the first. As a grocery-shop the space should be heated or cooled effectively. For that reason the second method would demand higher volume to heat and this would be aimlessness. In addition, humidity will be reduced owing to the ventilation of the attic. The used insulation stuff for the construction is natural fibre like sheep's wool and also plywood and felts coverings were placed. The thickness is 5cm and the Thermal Resistance (R) 1,22 m²K/W which lead

to a new U-value for the roof much lower than the initial one, 0,555 W/m²K. (Energy service, September 2010)

5.3.2 Double glazed windows

Infiltration rate reduces considerably the energy performance of a building. The openings contribute to high energy, heating and air losses and for that reason the windows should change. A historic building should not affects its external appearance and that is why the changes must be restricted only in the windows. The metallic frames without thermal break will remain. The existing place of activity has single glazed windows, and their position take double glazed windows and air gap of 12mm.



Picture 17: A double glazed window.

5.3.3 HVAC systems and Lighting

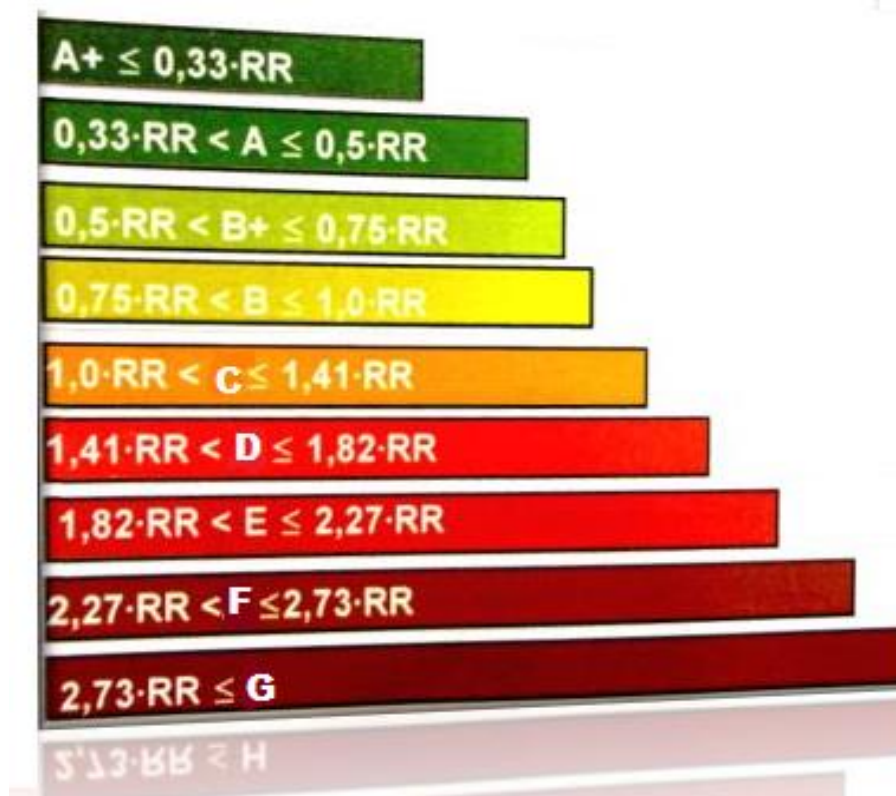
The target remains the same here, control the energy consumption and succeed better performance. The existing heating and cooling system, central oil boiler and air conditioning respectively, lost space from a better solution, a heat pump. The heat pump is therefore uses the environment to warm or cool a space. The use of electricity is only required in the process of pumping heat and the consumer pays only the cost of electricity required for pumping. Most heat pumps are considered renewable energy source (with a COP above 3.3) and draw the greatest amount of energy required from the environment. In our case the used heat pump is inverter and the refrigeration and thermal power can reach 16kW, with COP~3, 5 and EER~2.8. (Anon., 2013)

The natural lighting of the construction reaches the 65%, high because of the number of the openings. Even though, the building has incandescent lamps which are older generation and clearly insufficient. This may be understood from the installed power which reach the 6,64kW. To reduce the consumption the project aims to supply the lighting with LED lamps. Now the installed power drops to 2,2kW. As we will emphasize in the results, lighting can affect valuable the energy performance of a building.

5.3.4 Used software

The special TEE-KENAK software was developed by the Team of Energy Saving Group in Greece, Institute of Environmental Research and Sustainable Development (IERSD) of the National Observatory of Athens (NOA) in the frame of program of collaboration with the Technical Chamber of Greece (TEE).

This software implements the necessary algorithms for calculating the energy performance of buildings in Greece, based on the methodology of the European standards (ELOT EN ISO 13790, etc.) as well as on the relative national models and the corresponding TEE. Furthermore, the software is used for the energy audit process in order to calculate energy efficiency and energy classification of buildings in order to issue the Energy Performance Certificate - SMO. It is also used in the preparation stage and submission of the study and only for energy efficiency calculations and energy rating of the building in order to have a common methodology and consistency of study results with those of the energy audit after the completion of construction of the building. The Energy classes, in connection with the Primary energy are in the next Figure. (Picture 18)



Picture 18: *Proposal of ratings of buildings for different classifications. (Greece).*

5.4 Results

5.4.1 Results of the energy performance before the interventions

After having collected all the data and the existing situation of the building, we ran the software and some remarkable results came up. In the next tables the outcome is summarized. (Table 1, Table 2, Table 3) As we can notice the energy class is E, which means that the building is in energy topic totally inefficient. The primary energy consumption which contains the energy requirements for the conversion of primary sources of energy into forms useful for the final consumer, amounts to 429 kWh/m^2 and consists of the heating, the cooling and the lighting. We can notice that the energy consumption of the Domestic Hot Water is zero and this is due to the use of the building. Our warehouse-shop does not demand any hot water for any purpose. To continue with, Final Consumption is primary energy without the quantities of energy which is required to

transform primary sources into proper forms for final use. In the examined building the total energy consumption is 229, 3 kWh/m².

As we have shown previously, the CO₂ emissions cause problems and participate strongly in the energy performance of a building. In our case CO₂ emissions reach the 135, 9 kg/m², 43, 5% higher than the reference building, a building designed to be energy efficient. Moreover, the used fuels are oil and electricity and the total fuel consumption is 233, 7 kWh/m². To sum up, we the software run a feasibility analysis where finds the operational cost. The amount is 9.750€, which seems to be really in high levels compared to a new building. This easily explains the bad inefficient use of the construction.

Table 1: *The energy class of the building and the primary energy consumption of the existing situation.*

Primary energy consumption [kWh/m ²]	Examined Building
Heating	171,5
Cooling	124,3
Domestic Hot Water	0
Lighting	133,2
Renewable Energy Sources	0
Total	429
Ranking (Energy Class)	E

Table 2: *CO₂ emissions and fuel consumption at the existing situation.*

Energy source	Total Final Consumption [kWh/m ²]	Fuel Consumption [kWh/m ²]	CO ₂ Emissions [kg/m ²]
Cooling-Electricity	42,9	102,4	101,3
Heating-Oil	140,6	131,3	34,7
Lighting	45,9	-	-
Total	229,3	233,7	135,9

Table 3: *Energy demand of the existing building.*

Energy demand [kWh/m ²]	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Annual
Heating	21,9	13,5	7,5	2,3	0	0	0	0	0	0,6	6,2	17,8	69,5
Cooling	0	0	0	0	0	14,6	26	22,7	0	0	0	0	63,3

5.4.2 Results after the proposed measures

The retrofit project managed to improve the existing situation considerably. First of all the energy class climbed to *B*, showing that the building can be more functional and the energy performance much better. The primary energy consumption has been declined to 152, 3 kWh/m² and consists again of the heating, the cooling and the lighting. In addition, the designed shop's final Consumption drops to 52, 5 kWh/m². In our case CO₂ emissions reach now 53, 8 kg/m². Moreover, the used fuels in this occasion is only electricity and the total fuel consumption is 54, 4 kWh/m². In the end, a feasibility analysis stays to the operational cost of the building. The amount is 2.553€, which is significantly lower than the initial operational cost. The following tables summarize again the results.

Table 4: *The energy class of the building and the primary energy consumption after the interventions.*

"Primary energy consumption [kWh/m ²]"	Examined Building
Heating	54,7
Cooling	51,6
Domestic Hot Water	0
Lighting	46,1
Renewable Energy Sources	0
<i>Total</i>	<i>152,3</i>
<i>Ranking (Energy Class)</i>	<i>B</i>

Table 5: CO₂ emissions and fuel consumption after the interventions.

Energy source	Total Final Consumption [kWh/m ²]	Fuel Consumption [kWh/m ²]	CO ₂ Emissions [kg/m ²]
Electricity	36,6	54,4	53,8
Lighting	15,9	-	-
<i>Total</i>	<i>52,5</i>	<i>54,4</i>	<i>53,8</i>

Table 6: Energy Demand after the interventions.

Energy demand [kWh/m ²]	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Annual
Heating	11,7	8,4	4,8	0,7	0	0	0	0	0	0,1	3,7	9,6	39
Cooling	0	0	0	0	0	6,8	12,1	11	0	0	0	0	30

6 Discussion and Conclusions

In this paper, the results show different aspects and give the opportunity for an optimistic view of the interventions. Someone will say that these changes are too good to be true and the energy performance has changed dramatically and rapidly. Even though, considering the fact that these interventions are the most familiar and logical, the energy efficiency has been enhanced in the right way.

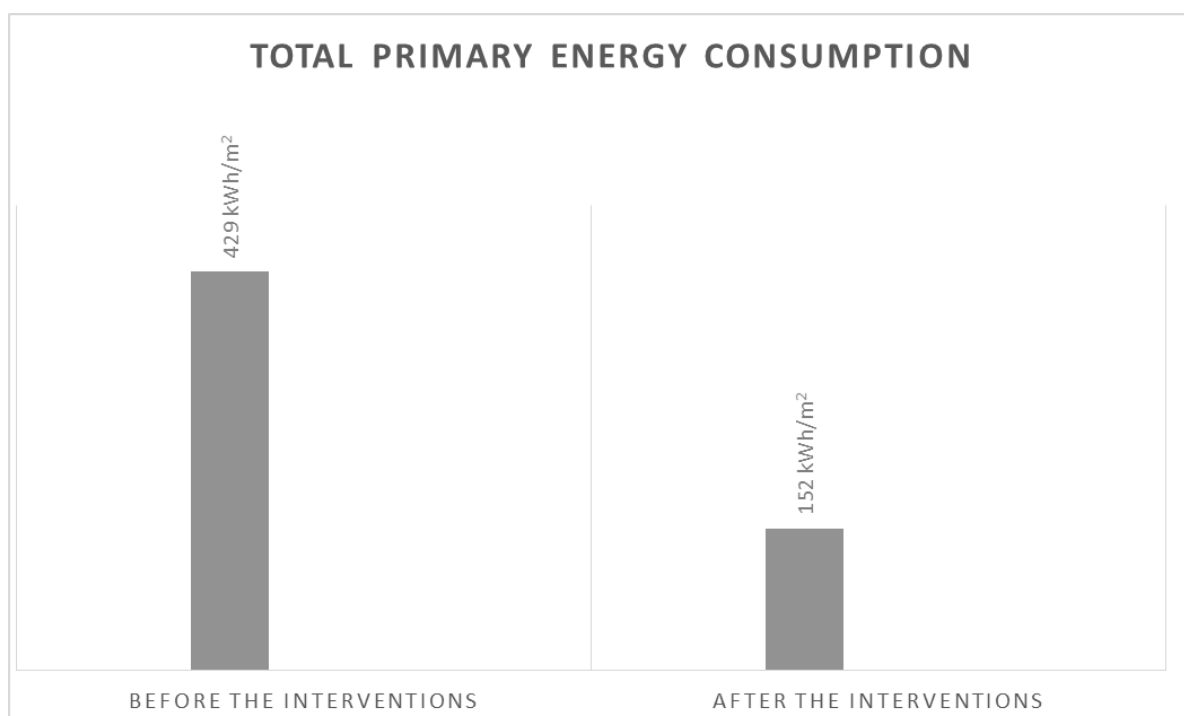
The analysis has considered a distinct retrofit option as a standalone package. The major point is not to put into action a suite of separate unconnected refurbishment adaptations, still to consider the impacts of combined reworking. For example the internal insulation of the walls may be able to deal with moisture problems after years, but the effect of internal insulation with barrier on ventilation rate is doubtful. The last solution may require further ventilation if moisture firstly moved in from external walls in a systematic rate.

Having simulated the proposed measures, the used software resulted an achievement of “B” energy class, instead of “E” which was the initial situation of the building. This may seem a big success but it is not. Every single change separately and all the changes together, help to acquire energy efficiency. The interventions were simple and included a completed bundle. Internal wall insulation, roof insulation, window’s change and HVAC systems lead to a whole upgrade of the building.

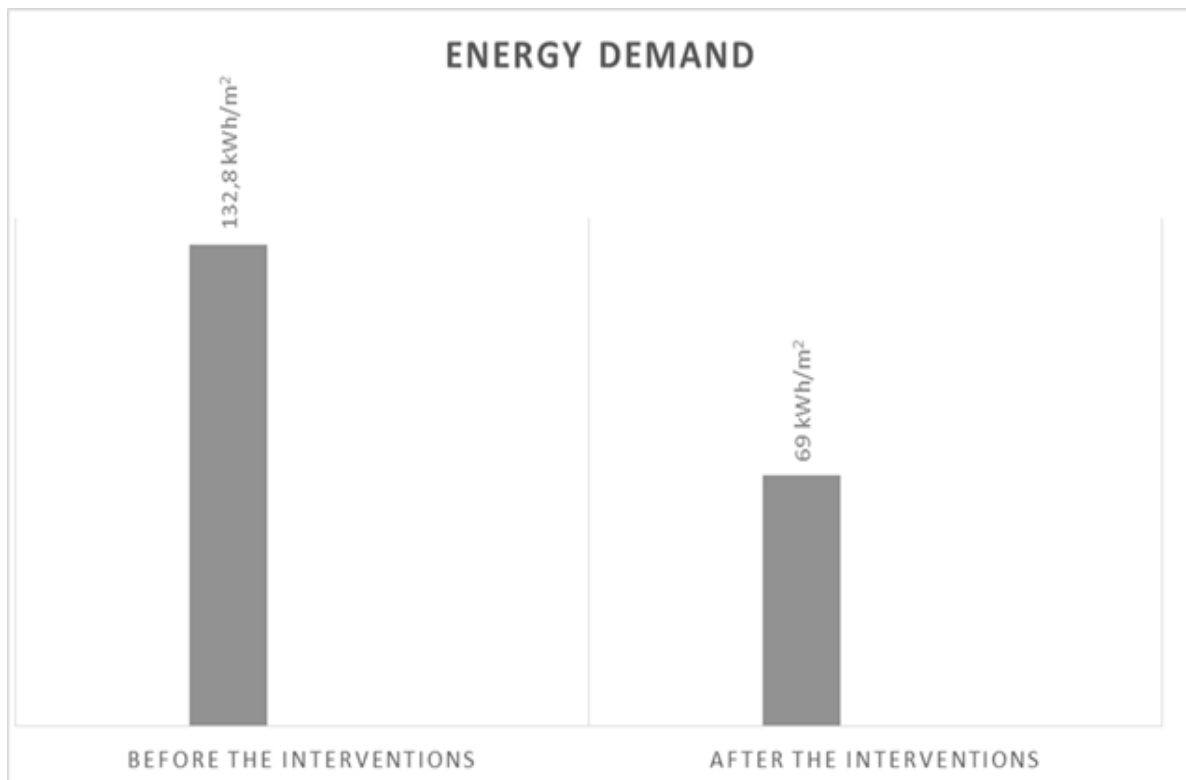
The walls were built with the used materials of those old years, meaning that there was not any insulating material or anything else but bricks. For that reason the internal insulation was unavoidable. As mentioned before, the external insulation could bring better results but the historical value does not allow to make such interventions. To close the subject of insulation, the pitched roof has been also insulated in order to avoid losses and addition heat demand. In addition, it was vital to propose a change of the single glazed windows to double glazed. The infiltration rate would be reduced and therefore

the energy losses would be restricted. Finally the HVAC system play considerable role in a building. For that reason the oil boiler gave the place to a heat pump which is more economical, more environmental friendly and cover also the cooling demands of the building.

In the next graphs a comparison between the situation before and after the interventions will be presented in order to have a better eye on the results. The first graph (Graph 1) presents the total change of the primary energy from which also depends the energy class of the building and the energy efficiency generally. The reduction stands at approximately 65%.



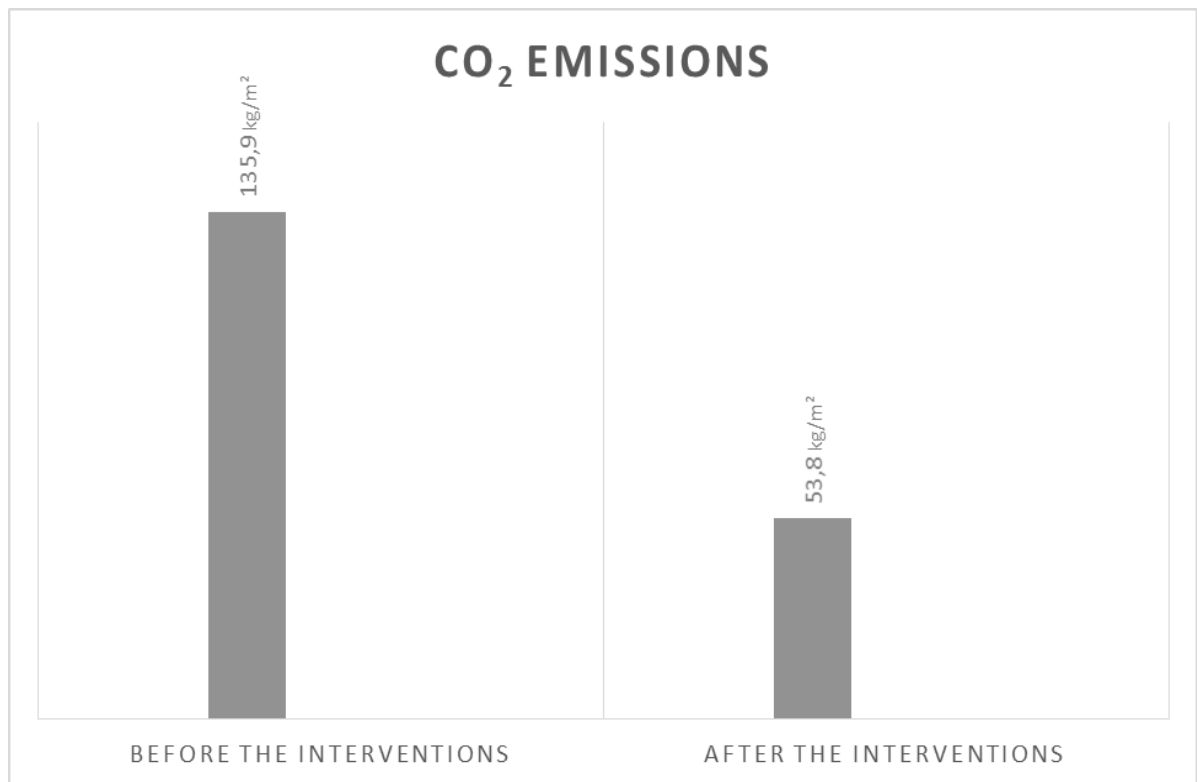
Graph 1: *Primary energy consumption before and after the interventions.*



Graph 2: *Comparison of the energy Demand before and after the interventions.*

The graph below shows the energy demand. (Graph 2) It is obvious that the reduction is great. The building now requires almost 50% lower energy than before and this is a great key for the energy performance.

CO₂ emissions for buildings built before 1919, reach the 86 kg CO₂/m². Despite this information, a work done by Moran, has displayed that the EHS can overestimate the energy use of a historic construction by 44%. (Moran, 2012) But from a logical point of view, it is clear that a historic building could play a great role in attaining emissions aims. In the next graph (Graph 3) someone can notice the huge reduction on CO₂ emissions after the interventions. CO₂ emissions after the renovation project are more than 60% lower than before. To this reduction contributes importantly the fact that the heating and cooling systems now consist of a heat pump and not of oil boiler.



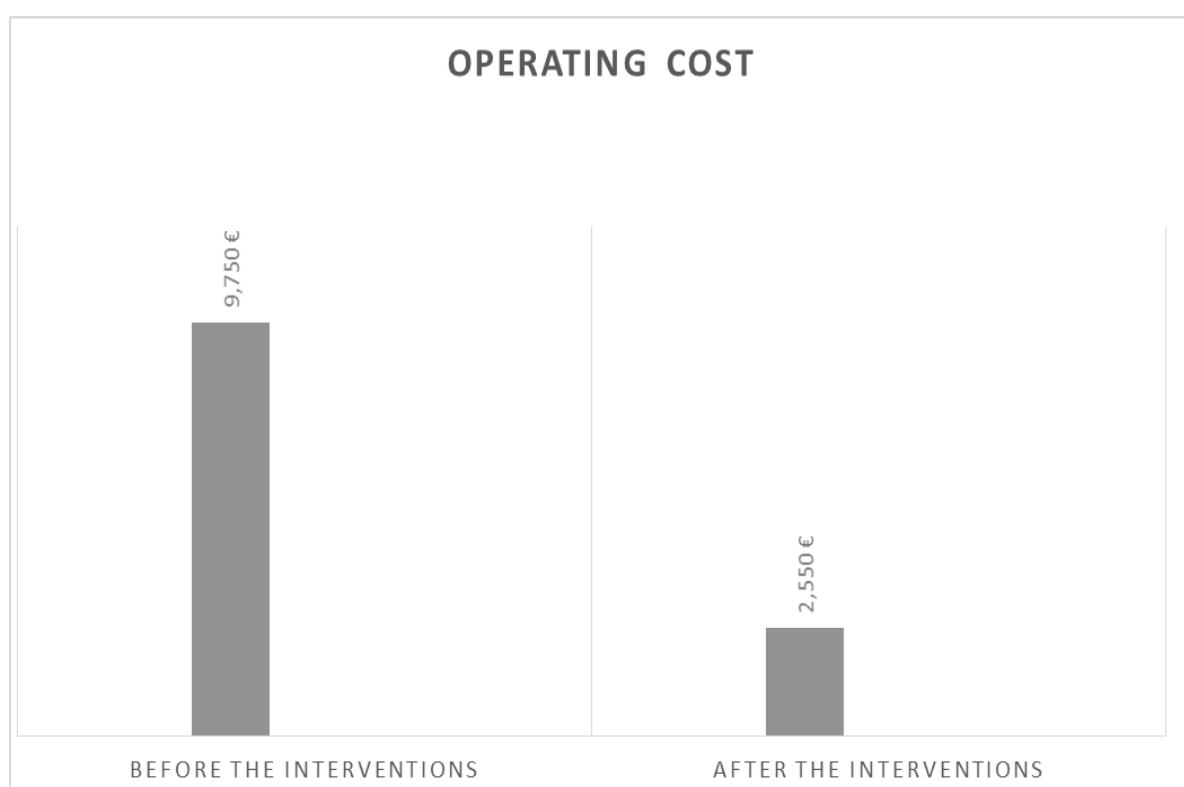
Graph 3: *CO₂ emissions before and after the interventions.*

Lighting is really important in a building, specifically when the constructions are intended for a shop or a restaurant. In our case the old lamps were replaced by new LED lamps and the reduction in the installed power was great. It is important to mention that the replacement of lamps contribute considerably to the energy performance. To check this, we have ran again the software without changing the lamps, the rest interventions are taking place, and we notice that the energy class reached “C” and not “B”. For that reason lighting can affect the energy efficiency of the building and can improve greatly the performance.

Renewable energy sources participate and penetrate last years in many constructions and buildings. Especially in new houses and buildings under renovation Res have great role. As we have seen earlier in literature review, many projects use Res as a key in order to enhance their performance. This is logical and useful because Res are the most ecological solution. For the examined building, the first thought was to install a roof PV system, aiming to cover the energy demand. This would be the most ideal solution in the energy efficiency point of view but the appearance of the building would change.

This kept the proposal only an idea. We should not forget that in a historic building the most challenging part is to keep the cultural heritage total intact.

Finally we should not forget to discuss the operational cost. (Graph 4) Even though this dissertation has not studied the economic point of view, the operational cost has decreased significantly due to the more profitable solutions. The maintenance and the expenses will be more efficiently economic and give the opportunity for a more tempting use of the building with more opportunities for investment.



Graph 4: The operating cost before and after the interventions.

To conclude, this dissertation aimed to present a proposal which is realistic and economic. Although the project demands further occupation, I believe that is a good start and a good idea. Finally, Ladadika area has over 100 buildings under operation. If every building separately enhance its performance, the objectives for reduction in consumption and CO2 emissions would be achieved more easily.

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